



Annual Reports :: Year 6 :: University of Rhode Island

Team Reports: University of Rhode Island

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Executive Summary

Principal Investigator: Steven D'Hondt

The University of Rhode Island (URI) team of the NASA Astrobiology Institute (NAI) works to gain a fundamental understanding of Earth's subsurface life. Our principal research objectives are to understand (1) the subsurface microbial ecosystems of marine sediments, (2) their role in Earth's biogeochemical cycles, and (3) their relevance to the search for life on other planets. Our investigators are based at URI, Woods Hole Oceanographic Institution (WHOI), and the University of North Carolina at Chapel Hill (UNC). To effectively accomplish our objectives, URI team researchers collaborate with each other and with scientists at other institutions throughout the world. Our current collaborators include members of other NAI teams at the NASA Ames Research Center, the Marine Biological Laboratory (MBL), and Pennsylvania State University. Other collaborators include scientists at the Massachusetts Institute of Technology, the University of Bremen (Germany), the Max Planck Institute for Marine Microbiology (Germany), the Scripps Institution of Oceanography, the Japan Marine Science and Technology Center, Roger Williams University, the University of Aarhus (Denmark), and other institutions throughout the world. To gain access to subsurface environments, URI team members participated in international expeditions through the Ocean Drilling program (ODP) and its successor, the International Ocean Drilling Program (IODP).

Members of our team at URI principally focus on studies of subsurface metabolic activities and biogeochemical fluxes. To further these studies, team members are developing new techniques to study the activity and physiology of energy-limited microbial communities. For one example, members of our URI group are working to develop a robust tritium-based method for quantifying metabolic activity at rates that are well below the detection limit of current radiotracer techniques (Soffientino et al., 2004). If their effort is successful, this assay will be the first measure of enzymatic activity applicable to environments with extremely low levels of metabolism. For another example, in the last year, we developed a numerical model that uses profiles of chemical and physical properties to quantify metabolic rates at depth (Manor et al., 2004). Although our model is still being refined, it is already flexible enough to quantify complex variation in rates throughout sediment columns of great depth. Other activities by the URI group include exploratory work on a novel cell extraction, analyses of adenosine triphosphate (ATP) concentrations and dissolved organic

compounds in deep subseafloor, and quantification of biogeochemical fluxes and thermodynamic equilibria of biogeochemical reactions.

Our biogeochemical studies demonstrate that metabolic interactions in deep subseafloor ecosystems are complex (e.g., D'Hondt et al., in review). For example, several hypothetically competing processes, including metal reduction, sulfate reduction and methanogenesis, commonly occur in deeply buried sediments. At some sites, aerobic communities live deep beneath anaerobic communities because the underlying basaltic aquifer supplies oxygen and nitrate to the deep sediments. The sedimentary communities may, in turn, fuel life in the underlying basalts by supplying electron donors and nutrients.

Closer study of some hypothetically competing processes suggests that they may actually cooperate under some subsurface conditions. For example, sulfur reduction and iron reduction co-occur with low and relatively constant free energy yields in some deep subseafloor sediments (Figure 1) (Wang et al., 2004). Positive feedback between these reactions [e.g., co-precipitation of their waste products Fe(II) and S²⁻] may help to sustain them (Wang et al., 2004).

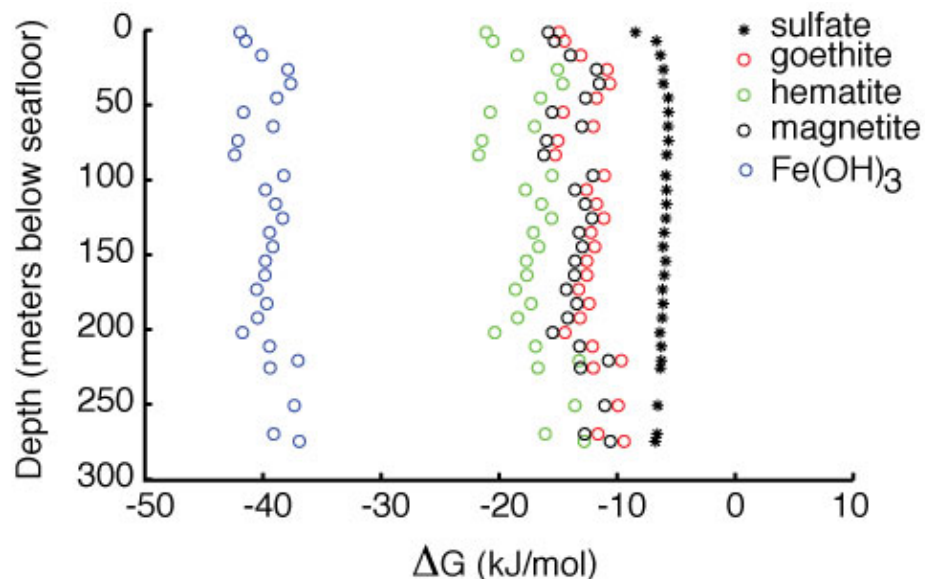


Figure 1. Estimates of free energy yields (delta G) from some iron-reducing reactions and a sulfate-reducing reaction at ODP Site 1226 (Wang et al., unpublished). The iron-utilizing yields assume that the solid phases are present and that dissolved Fe (III) concentrations are at equilibrium. At depths where these assumptions are incorrect, in situ delta G values will be more positive than the estimated yields.

Team members at UNC have focused primarily on exploring the taxonomic composition of subseafloor ecosystems. Studies of the UNC group have focused on (1) the taxonomic composition of low-biomass communities in organic-poor open ocean sediments, (2) the taxonomic composition of methane-oxidizing prokaryotic communities, and (3) with Virginia Edgcomb

(NAI Postdoctoral Fellow at MBL), on the environmental stress tolerance of hyperthermophilic vent archaea. To obtain DNA from the low-biomass sediments, we have continued to develop DNA isolation methods. Consequently, we now have an array of DNA isolation procedures that allow expansion of our archaeal 16S rDNA sequence datasets from these low-activity sites. However, it should be noted that the results of these analyses are near the sensitivity limit for molecular (nucleic acid-based) procedures.

Our studies of 16S rRNA genes indicate that two uncultured archaeal lineages, the Deep-Sea archaeal group (DSAG), and the Marine Benthic Group A (MBGA) are cosmopolitan members of subseafloor sedimentary communities (Lauer et al., 2004). Another uncultured lineage, the marine group I archaea (MGI), is ubiquitous in the marine water column. 16S assays and functional gene analyses indicate that known methanogens are unexpectedly scarce in subseafloor sediments (Inagaki et al., 2003; Mark Lever, unpublished), although methanogenesis appears to occur in all subseafloor sediment columns (D'Hondt et al., in review).

Analyses of the communities in the consistently cold sediments of our lowest-biomass site to date, Peru Basin ODP Site 1231, yielded a highly diverse archaeal community that including members of several deeply branching lineages that were previously known only from hydrothermal vents (DHVE 6; the newly described Peru Basin cluster, the UCIIb cluster) (Sørensen et al. 2004) (Figure 2). This conspicuous occurrence pattern suggests that some phylotypes that were originally found in hydrothermal systems may not be indigenous to hot vent systems, but originate in cooler subsurface habitats from which they are flushed out as seawater is entrained into the hydrothermal circulation system (Sørensen et al., 2004). In other words, cold subsurface sediments may harbor seed populations of vent systems.

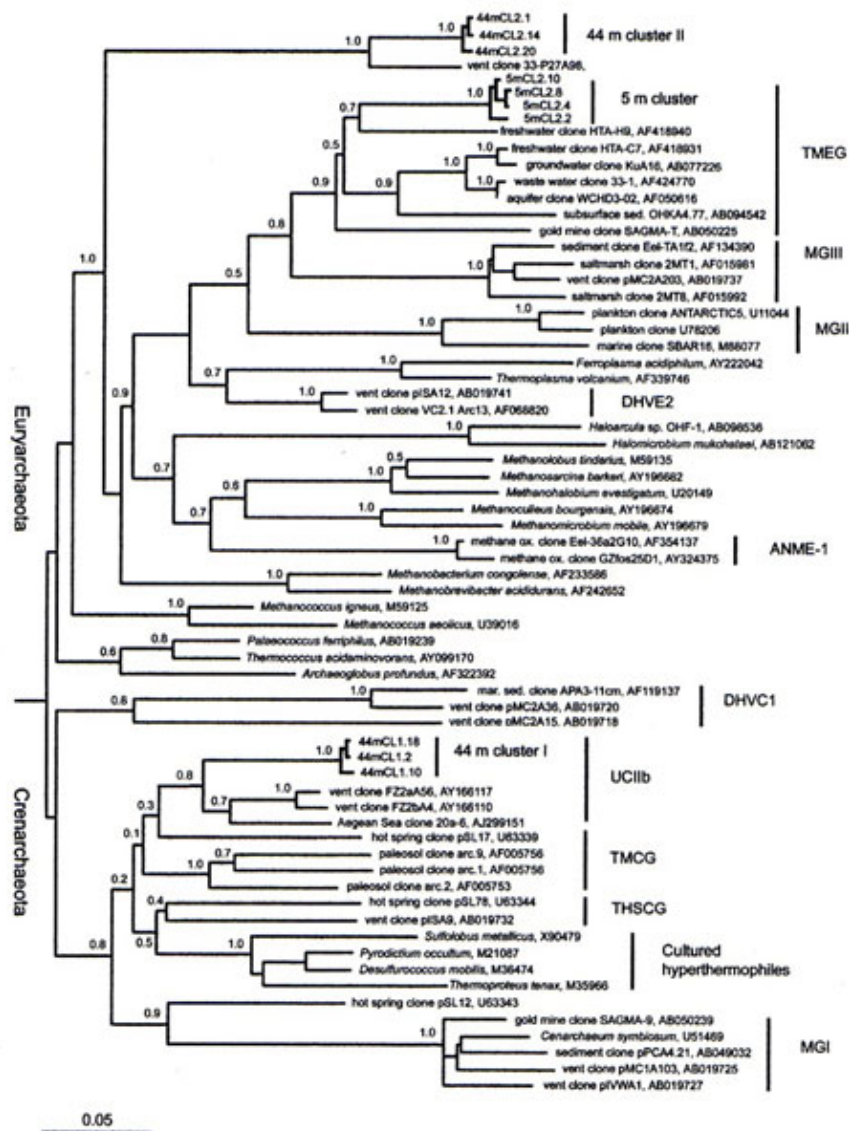


Figure 2. Novel archaeal lineages from subsurface sediments of ODP Site 1231, identified from 16S rRNA gene sequencing. Site 1231 differs from sites with higher biomass by containing unusual archaeal lineages that are in some cases related to 16S rRNA genes collected from hydrothermal vents (44 m cluster; UCIIb cluster). Figure from Sorensen et al. (2004).

The aim of our collaboration with Edgcomb was to define physiological adaptations or incompatibilities of vent archaea for growth or survival under vent and subsurface regimes. High concentrations of heavy metals were tolerated by hydrothermal vent archaea due to metal–sulfide speciation and formation of dissolved or solid metal–sulfide complexes that are biologically unavailable. Dissolved metal cations without adequate sulfide complexation remain highly toxic, even to vent archaea that specialize in this metal–rich habitat (Edgcomb et al., 2004). These experiments provide intriguing support for our hypothesis that metal and sulfur reducers may indirectly cooperate with each other.

We are continuing our survey of methane–sulfate interfaces and anaerobic methane–oxidizing communities in diverse environmental settings, such as the surficial sediments of the Guaymas Basin (Dhillon et al., 2004; Lever, unpublished), methane seep sediments in the Gulf of Mexico (Karen Lloyd, unpublished, in collaboration with Chris Martens and Laura Lapham of UNC Chapel Hill), and deep seafloor sediments (Lever, unpublished; Inagaki et al., 2003).

In all settings, 16S rRNA and functional key genes for sulfate reduction and methanogenesis are combined (if detectable) for a comprehensive picture of the microbial community. As much as possible, biogeochemical data are used to define ecological niches for each microbial community.

Team members at WHOI continue to principally focus on organic biogeochemical and isotopic signatures of life in subsurface environments. In collaboration with Roger Summons (MIT), team members at WHOI have shown that analyses of intact polar lipids (IPLs) can provide taxonomic specificity allowing distinction of prokaryotes at levels of species to orders. For example, their analyses provided the first evidence for live archaea in deeply buried sulphate–methane sedimentary transition zones (Sturt et al., 2004). In studies of natural ecosystems, the low selectivity of IPL analyses rapidly provides an unbiased view of the dominant microbial players.

Our studies provide strong evidence for biological production of ethane and propane in marine sediments (e.g., D'Hondt et al., 2003). Studies by team member Kai-Uwe Hinrichs and collaborators of isotopic compositions, abundances of potential reactants and products, and bioenergetic modelling point to a mechanism involving hydrogenation of acetate (and bicarbonate) to yield ethane and propane (Hinrichs et al., submitted). These reactions proceed close to the biological energy quantum and provide a previously unexplored sink for major products of fermentation.

Team members John Hayes, Sean Sylva and Helen Sturt, with collaborators Bradley (MIT) and Summons, have shown that lipid extracts from samples of the Lost City Hydrothermal Field are dominated by glycerol ethers from archaea and bacteria. They have also discovered that these ether–linked lipids have remarkably high δ values (Kelley et al., submitted). This discovery raises the possibility that seawater DIC is the carbon source used by both the archaea and sulfate reducers. This could be a consequence of the high concentrations of H_2 supporting simultaneous, independent growth of both groups.

With collaborators Rothman and Summons, Hayes used biogeochemical analyses and modeling to assess the isotopic dynamics of the Neoproterozoic carbon cycle. They conclude that high concentrations of dissolved organic carbon might have played a major role in shaping the isotopic record (Rothman et al., 2003).

Some of our activities are closely integrated with the work of several collaborators at the University of Bremen. This integration is given special impetus by Hinrichs, who is a Marine Scientist at WHOI and a Professor at the

University of Bremen. For example, team member Lever and collaborators Verena Heuer (University of Bremen) and Fumio Inagaki, Japan Agency for Marine–Earth Science and Technology (JAMSTEC), are currently participating in the first IODP expedition (at the Juan de Fuca Ridge). Team member Steven D'Hondt was a co–proponent of this expedition. Samples from these geothermally heated sediments with high organic contents will complement our ongoing activities at cold sites. The work of Julius Lipp (University of Bremen) complements our team's work at WHOI on IPLs in the deep biosphere. Lipp primarily focuses on tracing microbial metabolism by isotopic investigations of bulk IPL fractions that are representative of the living prokaryotic community. Our previous development of analytical procedures for rapid determination of isotopic compositions in chemical intermediates of microbial metabolism (Hayes, Hinrichs, Hmelo) is now complemented by work at University of Bremen, where Marcus Elvert, Hmelo and Hinrichs are testing a new procedure that involves direct coupling of HPLC to an isotope–ratio MS.

To build greater understanding and interest in astrobiology and study of subsurface life by professional scientists, URI team members served prominent roles at several international conferences. For example, team member David C. Smith chaired the session on *Life in Extreme Environments* at the UK–US Frontiers of Science Conference in, Cambridge, UK (June 20–22, 2004). This meeting was jointly sponsored by the Royal Society and by the U.S. National Academy of Science. D'Hondt delivered Distinguished Professor Lectures in the *Short Course on Geomicrobiology*, Shanghai (June 13–19, 2004). These lectures were hosted by Tongji University, sponsored by IODP–China, and attended by Earth and life scientists from throughout China. D'Hondt also served as a Keynote Speaker at the *International Workshop on Geomicrobiology – a research area in progress* (hosted and sponsored by the University of Aarhus, Denmark) in January, 2004, and as an Invited Speaker at the 8th Annual DOSECC Workshop on Continental Scientific Drilling, at Rutgers University (USA) in May, 2004 [hosted by the DOSECC (Drilling, Observation and Sampling of the Earth's Continental Crust) organization and sponsored by the U.S. National Science Foundation].

Graduate, undergraduate and post–doctoral education and research are integral parts of the URI team's mission. During the Year–6 report interval, our active research team included four post–doctoral scholars (Antje Lauer, Ketil Sørensen, Bruno Soffientino, and Sturt,), four graduate students (Lever, Lloyd, Colleen Mouw, and Guizhi Wang) and six undergraduate students. All of these individuals played vital roles in our ongoing program.

To introduce astrobiology to young scientists with particularly strong potential, each year the URI team initiated nationally competed summer research fellowships for upper–class (junior or senior) students to work with URI investigators on projects of astrobiological significance. Two summer fellows (Uri Manor and Beverly Chen) were selected in 2003 and two additional summer fellows were selected in 2004 (Kristopher Carlson and Kelly Hanks). Chen worked with D.C. Smith on developing and applying ATP assays to subseafloor sediments. Manor worked with Scott Rutherford, Wang, and D'Hondt to develop a modeling program for quantifying net rates of microbial activity in deep subsurface sediments. Carlson is working with Soffientino and

D.C. Smith to develop and test protocols for separating live prokaryotic cells from subseafloor sediments. Hanks is working with D'Hondt and Arthur Spivack to quantify possible rates of radiolytic hydrogen and oxygen production in subseafloor sediments and rocks.

To build a deeper institutional base of astrobiology awareness among undergraduate and graduate scientists and engineers, URI astrobiologists expanded the academic programs of their home institutions by integrating astrobiological themes into existing courses, and by offering a new URI graduate course titled "Astrobiology" (Autumn, 2003). To introduce our work and the field of astrobiology to the broader public, URI team investigators gave public presentations and lectures at a variety of universities and other venues. To disseminate our work and its relevance more broadly, in the Year-6 interval the team continues to maintain a website on URI astrobiology efforts in research and education (<http://www.gso.uri.edu/astrobiology>).

In short, research, education and outreach by the NAI URI Team and its collaborators continue to steadily advance knowledge and awareness of life deep beneath Earth's surface, its role in Earth's surface processes, and its relevance to the search for life on other planets.

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